EVBUM2290/D

Evaluation Kit for Power Line Communication User's Manual

ON Semiconductor®

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EVAL BOARD USER'S MANUAL

Introduction

This manual describes the evaluation kits (EVK) for the power line communication (PLC) modems from ON Semiconductor.

In addition, we provide some information on how to proceed to an application design (see *"Application Design Maunal"*).

The information in this manual is focused on the NCN49597 and NCN49599 modems. However, large parts also apply to the AMIS−49587.

In addition, this manual only describes the downloadable firmware: either the IEC61334−5−1/IEC61334−4−32-compliant firmware or the PL110 firmware[1]. To determine which firmware variant is optimal for your application, refer to [18, 19].

To get started immediately with a new evaluation kit, first read *"Safety"* section. Then install the required driver and software on a computer (see *"Driver Installation"* and *"Terminal Installation"*); connect two evaluation kits to mains and to the computer; and start configuring the modems (see *"Starting the Terminal"*).

EVALUATION KIT USER'S MANUAL

The performance of power line communication (PLC) strongly depends on the environment. Testing in the real world at an early stage is therefore essential. To support customers looking for a PLC solution an evaluation kit (EVK) has been developed.

The evaluation kit allows the user to set up communication between two modems over the power line under control of a PC.

In addition to performance evaluation, the EVK enables an early start of user software development.

The design of the boards is also a good starting point for an application design.

A standard evaluation kit contains two enclosures (each with a motherboard and a daughterboard), two USB cables, a "Getting started" guide, a test report, motherboard and daughterboard schematic, and this manual.

Safety

By necessity a large part of a PLC modem board is directly connected to the mains. Special care must be taken due to the high voltages present (up to 350 V). After the board is disconnected, these voltages linger for some time on the capacitors.

Always use an isolation transformer during experiments or measurements on the high voltage section or when the enclosure is removed.

It is recommended that the evaluation kit is only operated by skilled technicians, especially if the board is used outside of the enclosure.

When the fuse has blown, replace it with a suitable type. A fast fuse of 1.6 A or less is recommended[2].

The evaluation kit is designed for single-phase operation only, i.e. with the power cable connected from neutral to phase. Operation across two phases is not possible.

Evaluation Boards

The evaluation circuit is split up in a motherboard and a daughterboard (Figure 1). Refer to [11, 14, 15] for the full schematics.

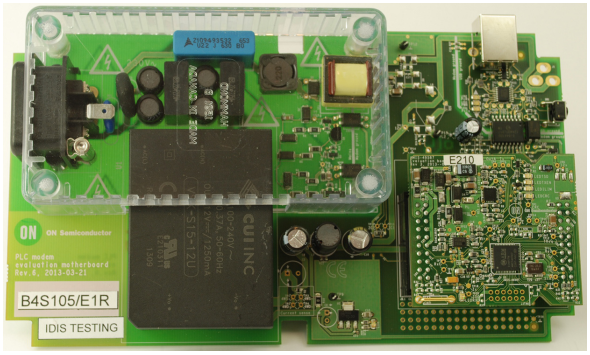

Figure 1. Evaluation Boards: Motherboard and Plugged-on Daughterboard

[1]Information on the ROM firmware embedded in the AMIS−49587 may be found in [12]; the terminal application this modem is described in [10, 13]. Please note that ON Semiconductor strongly recommends users of the AMIS−49587 ROM firmware to upgrade to the NCN49597 with downloadable IEC firmware.
Upgrading AMIS−49587 designs to NCN49597 is easy and is described in [16, "Driver Installation" section].

[2]The high current rating does not stem from the power supply, which consumes 150 mA at most, but from the PLC signal.

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The motherboard contains the power supply, mains coupling circuit (including the zero-crossing detection) and an USB-to-teletype converter.

The daughterboard contains the modem itself, the power amplifier, the receive and the transmit filter and the protection circuit. Refer to *"EVK Filter Responses"* section for a list of available daughterboards[3].

Power Supply

An enclosed switching mode power supply (SMPS) converts the AC voltage to a 12 V, 1 A DC voltage. An input filter is required to comply with EME regulations. Additionally, the impedance on the line must be sufficiently high for the PLC frequencies. This precludes the use of a capacitor directly between the phases. Instead, a fourth order LC filter is used. For more information refer to the application note "PLC modem power supplies".

The input range of the power supply is 85–264 VAC and 120–370 VDC[4]. The coupling stage should work with any power line with a voltage of less than 260 VAC (frequency 60 Hz or less) and 370 VDC.

Operation with a power line voltage above the given range is not safe.

Operation with a voltage below the given range is possible, provided the AC−DC power supply is isolated. This may be done by desoldering the first inductor pair of the power supply filter. The board must then be fed from an external 12 VDC power supply through J1[5].

The 12 V supply is used directly by the line driver during transmission.

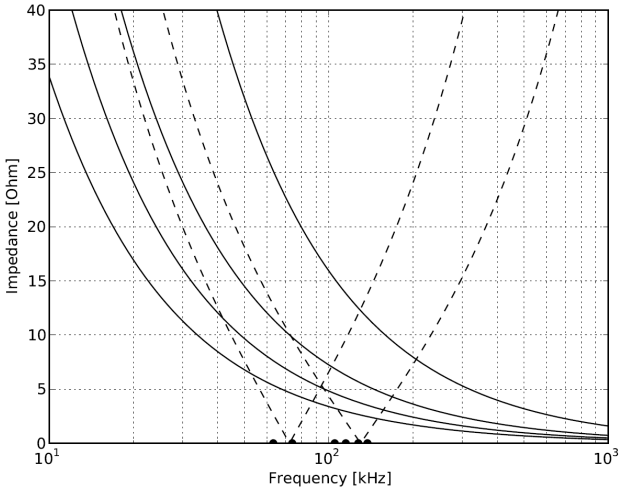

Figure 2. Impedance of Typical Coupling Circuits: 100, 220, 330 and 470 nF Capacitors (Solid Lines, Top to Bottom); 220 nF + 22 μH and 150 nF + 10 μH (Dashed, Left resp. Right)

A 3.3 V low-drop out voltage (LDO) linear regulator supplies the modem itself, the digital circuits and the additional opamp(s) on the daughterboard.

Zero Crossing Detection

The low-cost zero-crossing detection circuit proposed in [20] is included on the motherboard. In addition, revision 6 motherboards and later also provide footprints to populate the low-power zero-crossing circuit.

Typically, a delay of 35 ±5 μs with a jitter of 1 μs is measured between the actual zero-crossing signal and the digital output of the optocoupler.

Mains Coupling

The motherboard contains the coupling circuit with the mains: high-voltage coupling capacitor, inductor (optional) and transformer.

The coupling capacitor is required to block the 50 or 60 Hz mains voltage. Values of 100–470 nF are typical. The impedance of the capacitor near PLC frequencies is shown in Figure 2, solid lines.

The IDIS carrier frequencies (63.3 and 74 kHz) and the PL110 dual channel carrier frequencies (105, 115, 127.5 and 137.5 kHz) are also marked at the bottom of the graph.

Often, a lower impedance is desired at the carrier frequencies to allow more power to be coupled onto the mains. To this end a resonant coupling circuit (inductor and capacitor in series) may be used. Figure 2 shows the impedance of two coupling circuits: 220 nF + 22 μH and 150 nF + 10 μH[6].

The drawback of a resonant coupling circuit is apparent in Figure 2: away from the resonance frequency, the impedance is often higher than with a simple capacitor.

The coupling circuit fitted on the evaluation board depends on the frequency band. For IEC motherboards, a 220 nF capacitor is used with an optional inductor of 10 μH[7]. For PL110 motherboards, 330 nF is fitted.

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[3] If no daughterboard is available for the product or frequency band you are interested in, contact your sales representative to obtain tuned daughterboards.

[4] Consult the manufacturers datasheet for details: for the Mean Well supplies refer to [8]; for the CUI supplies to [1].
Note that the IEC standard and IEC firmware requires a mains zero crossing to synchronise transmission. Only the ONPL110 firmware can operate without zero crossing, if it is configured to do so (page 6).

[5] A footprint is provided but not fitted. Farnell 1737246 or equivalent may be used.

[6] In both cases, a 75 Ω resistor is added in parallel to the inductor to reduce the quality factor.

[7] Two inductor footprints are provided to allow changes. Note that inductor footprints are only present on revision 6 and later motherboards.

The capacitor and inductor can be changed easily. Any film capacitor with a suitable voltage rating and a lead spacing of 15[8] or 22.5 mm is suitable. The Epcos B32923[9] series or the Vishay MKT series is suggested. For the inductor, a sufficiently high saturation current must be selected to avoid distortion of the output signal. The Bourns SRR1260 series is suggested[10].

Four suitable transformers are shown in Table 1. Note that the PT10 transformer is not recommended for use with large signals, as the core saturates earlier than the other suggested models.

A footprint is provided for these transformers on the motherboard[11]. By default, only TF1 (ON−PLC−1 transformer) is populated. If you would like to evaluate one of the other transformers, contact your ON Semiconductor sales representative before ordering an evaluation kit.

The daughterboard contains the recommended protection circuit (refer to Application Design Manual for details)[12].

Table 1. TRANSFORMER FOOTPRINTS PROVIDED ON THE MOTHERBOARD

Manufacturer	Reference	Designator
Telkor	ON-PLC-1T2-001	TF1
Vacuumschmelze	T60403-K5032-X111	TF3
Wuerth Electronics Midcom	750313480†	TF4
Oxford Electrical Products	PT10*	TF2

†Wuerth can also provide customized versions to meet specific customer requirements.
*Recommended for 6 V operation only.

As noted in *"Power Supply"* section, the EVK is designed for a DC or low-frequency AC line with a voltage of 85–264 VAC and 120–370 VDC. For lower voltages, the coupling circuit is still usable, but it is recommended to disconnect the power supply from the mains input. For more optimal designs for DC lines, refer to part II.

Line Driver Enable Signal

A standard-compliant KNX PL110 stack needs to be able to transmit half-words. However, the NCN49597/599 can only transmit full bytes. As a workaround, a GPIO can override the TxEb signal. In the evaluation daughterboards this is made possible through the addition of R36 (Figure 3). During normal operation and at the beginning of a frame, IO is left in a high-impedance state. To stop the transmission IO3 is set high by the ON Semiconductor PL110 embedded software stack. This feature is not used by the IEC software stack, and IO3 remains available as a normal GPIO.

Serial Communication

Two UART signals, RxD and TxD, are provided to allow serial communication with the modem. In addition, a *transmission request* signal is provided to enable communication with ROM software of the modem and to enable uploading new embedded software over the UART interface.

Starting with revision 6, evaluation motherboards also allow triggering a hardware reset over the USB connection. Querying the error state of the evaluation kit is also possible.

To avoid parasitic communication paths and protect the computer connected to the evaluation board, the serial communication ground is galvanically isolated from the modem ground.

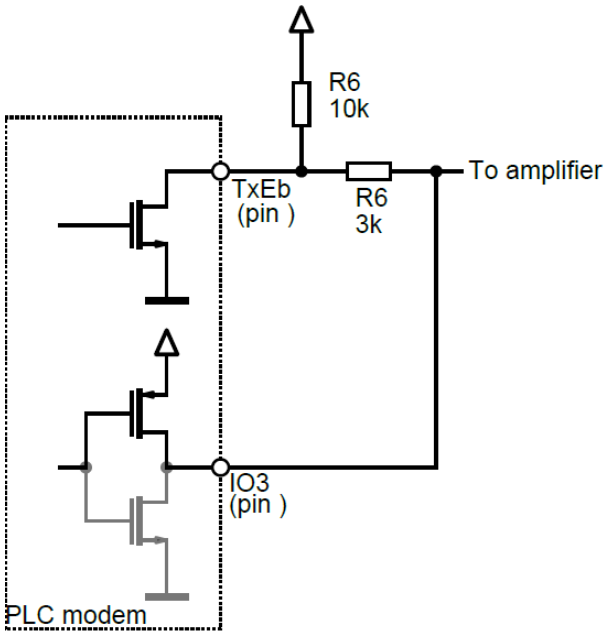

Figure 3. TxEb Control Circuit. The Transistor Drawn in Grey is not Used

Modern Boot Sequence

The boot sequence of the NCN49597/9 is controlled by the SEN and TREQ pins (refer to [16, 17] for details).

For the first, a solder jumper is provided on the daughterboard. By default, daughterboards are populated with the jumper set to ground.

The TREQ pin is controlled through the serial port.

Normally the firmware is loaded into the modem over the serial port.

[8]This lead spacing is only supported on revision 7 and later motherboards.

[9]Farnell order code for 220 nF: 9751335.

[10]Farnell order code for 22 μF: 1929699.

[11]Starting from revision 7. Motherboards revision 6 and earlier provided only footprints for the Telkor ON−PLC−1 and the PT10 transformer.

[12]For historical reasons, the decoupling capacitor on the secondary side and most parts of the protection circuit are located on the daughterboards. Although footprints for protection components are provided on the motherboard, they are not populated.

As an alternative, the bootloader in the modem can load the firmware from an attached SPI EEPROM or flash memory. Any memory chip may be used provided it supports the standard commands and it is addressed with a three bytes address. In practice, this will imply a memory size of at least 512 Mb as smaller memories typically use two-byte addressing.

An intermediate board with a flash memory is available for the evaluation kit, allowing the modem firmware to be loaded, without user intervention, when the modem resets. The flash memory can be programmed with any DIP8-compatible programmer. Please contact your sales representative for more information and to obtain an intermediate board.

Using the Evaluation Kit

To use the evaluation kit terminal, you will need a PC with Microsoft Windows XP or later. One PC can control multiple boards, but two PC's are usually required to test communication quality over a long distance.

You will also need two IEC C14 power cables to connect each evaluation board to the mains.

Driver Installation

The serial port is encapsulated over USB as a *virtual communications port* (VCP) by a converter chip. On Windows operating systems, specific drivers must be installed before this converter is recognized by the computer.

On Windows 7 and higher, installation normally starts automatically when the motherboard is first connected. This is indicated by the animated icon in the task bar (Figure 4). Note that installation can take a long time the first time an unrecognized device is plugging in − be patient[13]!

You can verify the state of the device by opening the *Device Manager* (Figure 6)[14]. After the driver has been installed successfully and the device has been configured by Windows, a new serial port will appear in the device manager (Figure 5) under the category *Ports (COM and LPT)*. The virtual serial port is ready to be used.

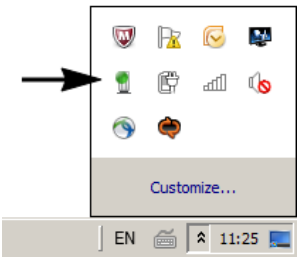

Figure 4. Notification Shown by Windows 7 during the Automatic Installation of the Driver of an USB-to-Serial Converter Chip

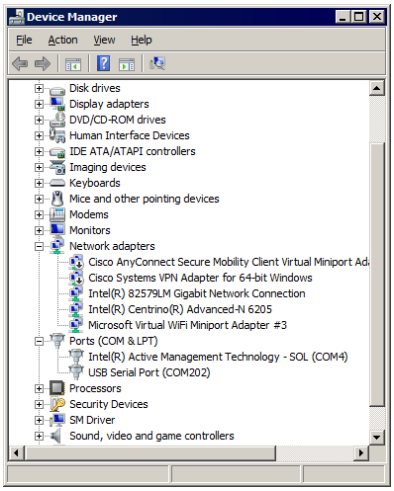

Figure 5. Windows Device Manager Showing a USB-to-Serial Converter Chip after Successful Installation

If the installation has not (yet) been completed, the device is shown with a yellow icon (as in Figure 6, under *Other devices*).

You will need to install the driver manually if the automatic installation fails.

- If you have a revision 5 motherboards, with a Microchip MCP2200 converter, you must download the latest version of the driver (MCP2200.inf) from the Microchip website. To install the driver manually, right-click on the device in the *Device Manager*, and select *Update driver software*. Please select "Install from a location on disk" and point the installer to the file you downloaded earlier.
- All other motherboard revisions use an FTDI converter. The easiest way to install the driver is the installation executable available from [5]. If you encounter problems during the installation, refer to [3, 4].

[13] If installation remains slow after the first installation of the driver, consider changing the order Windows uses to search device drivers. This may be done by right-clicking on *My Computer* → *Properties* → *Advanced* → *Hardware* → *Device Installation Settings*. Directing Windows to search for drivers on the computer first instead of through Windows Update will speed up device installation.

[14] Accessed by right-clicking on my *[My] Computer.*

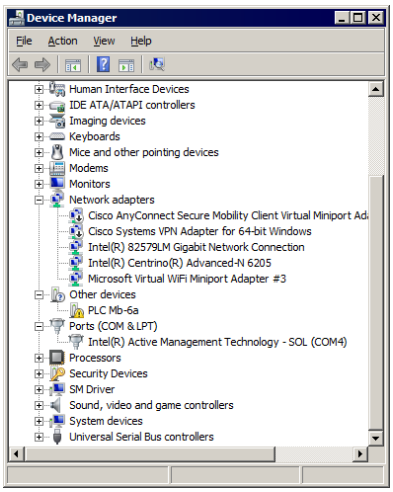

Figure 6. Windows Device Manager Showing a USB-to-Serial Converter Chip during Installation, or after the Installation has Failed

Terminal Installation

You should have received an installation program for the terminal you wish to use. If not please contact Software.Development@onsemi.com. Prior to starting this installer, you must install the .NET framework, version 4 or above. You can download an installer from the Microsoft website at [9][15]. It is strongly recommended to do this even if you have already a .NET framework installed. This ensures your .NET installation is up to date.

You must also install the Gtk# for .NET library from [21]. The exact version is important, so make sure to use the Gtk# installer supplied with the terminal installation program.

Subsequently, the PC software installer can be run; once completed, an entry will appear in your *Start Menu* allowing you to run the software.

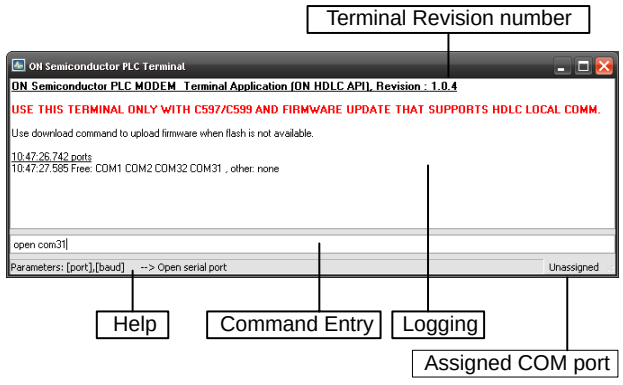
Terminal Revision number
ON Semiconductor PLC Terminal
ON Semiconductor PLC MODEM Terminal Application (ON HDLC API), Revision : 1.0.4
USE THIS TERMINAL ONLY WITH C597/C599 AND FIRMWARE UPDATE THAT SUPPORTS HDLC LOCAL COMM.
Use download command to upload firmware when flash is not available.
10:47:26.742 ports
10:47:27.585 Free: COM1 COM2 COM32 COM31 , other: none
open com31
Parameters: [port],[baud] --> Open serial port
Unassigned
Help
Command Entry
Logging
Assigned COM port

Figure 7. The Terminal Window

Starting the Terminal

The terminal application uses a serial port to communicate with the PLC evaluation board. The commands that are implemented by the PLC terminal application are translated into binary frames that are transmitted over the UART and expose a higher level, more user friendly, interface.

Separate terminals are provided for the different modem firmware variants: for the NCN49597 and NCN49599, terminals exists for KNX PL110 and IEC; for the AMIS−49587 another terminal is available for the IEC firmware running from ROM.

To start the terminal, navigate to the correct folder in the *Start Menu* and click the PLC terminal icon[16], then click on the icon. The terminal should start; if not please refer to *"Terminal Installation"* section and make sure you have all required libraries installed.

The PLC terminal application can be used to configure one single modem and transmit or receive data over the power line by entering commands in the command entry box (Figure 7). The terminal maintains a history of correctly entered commands. Pressing the up/down arrow keys will cycle through the list of entered commands. Help for partially typed commands is displayed in the status bar. To get a list of available commands with their explanation, enter the help command. A full list of supported commands appears in *"PL110 Firmware Commands"* and *"IEC Firmware Commands"* sections.

After connecting the modem to the PC you need to find out which serial port the modem is connected to.

We will use the *ports* command that lists the available and not available serial ports in the system. The easiest way to find the connected serial port is to issue the command *ports*, to unplug the board USB cable and issue *ports* again. The modem is connected to the serial port that disappeared from the list of available ports[17].

Plug the cable back in.

To open the serial port, issue the command *open* with two comma-separated parameters: the port name and the baud rate. As an example:

```
open  com213,  115200
```

The port will be opened and associated to the terminal. The baud rate is dependent on the daughterboard. AMIS−49587 boards use 38400 baud, except revision 3[18] which uses 9600 baud. NCN49597/9 boards use 115200 baud except older boards with a red solder mask which use 38400 baud.

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[15]Due to license restrictions, ON Semiconductor is unable to distribute the .NET installer with the PC software installer.

[16]This would be either *Programs → ON Semiconductor PLC Terminal for PL110 → ON Semiconductor PLC Terminal PL110*; or *Programs → ON Semiconductor PLC Terminal for IEC − Linky (HLDC API) → ON Semiconductor Terminal IEC − Linky (HLDC API)*.

[17]If nothing changes make sure your operating system recognizes the USB-to-Serial converter included on the evaluation board. Refer to "Driver Installation" section for more details.

[18]The daughterboard revision is noted in the silkscreen in the upper left corner of the board.

The *close*[19] command releases the serial port, allowing other applications to use it.

Configuring the Modem

Once the port is properly open and associated to a terminal it is possible to configure the device.

Note that the method used to do this depend on the firmware. This and the following sections describes the process for downloadable firmware. For the AMIS−49587 modem, refer to [12].

Firmware Download

If all previous steps were properly executed the *RxD* LED should start blinking slowly at 0.5 Hz (1 s on, 1 s off), indicating the ROM bootloader is running.

We will use this bootloader to download the right firmware[20] to the modem with the *download* command, specifying the path to the binary firmware file you received as an argument. Make sure you use the right file: the PL110 and IEC protocols require different firmware. As an example:

```
download D:\PLC\PL110.bin
```

This takes a few seconds to complete. Once the download has completed successfully, the *RxD* LED will blink twice as fast (1 Hz). If the download fails, ensure you are addressing the right serial port with the correct baud rate.

Parameter Selection

Before the modem can send or receive any data over the power line, it needs to be configured. The modem is configured by settings in the *Management Information Base* (MIB), a set of parameters that control every aspect of the firmware behavior.

The value of a specific MIB parameter can be retrieved with the *get* command. To change the value of a parameter, use the *set* command. The first parameter of both commands is the *Object ID* of the MIB parameter to access.

```
set 580C=159B
get 580C
```

First sets the MIB parameter MIB_R_FS1 to the hexadecimal value 159B; the second command will query the current value and should return the same 159B. As a result of the write operation, the space frequency of the first transmitter will change to 63.3 kHz[21].

A list of all MIB parameters may be retrieved with the *oids* command. In addition, the modem API spreadsheets in your PL110 and IEC terminal installation folders provide a detailed description of the MIB.

Use these settings to configure your evaluation board as described in *“Using the PL110 Firmware”* and *“Using the IEC Firmware”* sections.

Reset

To set all modem parameters back to the default values, use the *reset* command.

Sometimes a hard reset is required, especially if error messages start to pop up in the terminal window. In this case it is recommended to first close the serial port in the terminal with close. Then, push the reset button on the evaluation kit itself and restart from from *“Firmware Download”* section.

Using the PL110 Firmware

The PL110 protocol is based on a network model without a master node. The protocol supports collision avoidance and detection. Error correction and message reception acknowledgement are also included.

Configuring the Modems

Before any data can be sent or received over the power line, the modems need to be configured.

A minimal configuration when working with the MAC layer requires setting the individual MAC and domain addresses and activating the modem. As an example,

```
set 1000=20
set 1002=8
```

will set the MAC address to 0020_H and the domain address to 08_H.

By default, the PL110 firmware looks for a mains zero-crossing and synchronizes transmission with the mains. If synchronization to the mains zero crossing is not required or not possible (for instance, on a DC network), the MIB parameters MIB_R_MISC_ZCGEN_MODE *must* be set to 1. If this is not done, the modem will not be able to modulate or demodulate data.

Note that a small performance degradation must be expected for DC operation as the lack of shared timebase makes it more difficult for a received to demodulate the signal.

By default, a mains frequency of 50 Hz is assumed. If 60 Hz is used, the MIB parameter MIB_R_CONF_MAINS_FREQ must be set accordingly:

```
set 4101=1
```

Once configuration is complete, switch the modem into active mode:

```
set 4102=1
```

---

[19] As a reminder, all available commands are shown in the terminal log window when the command help is issued.
In addition, the full list of supported commands for terminals with downloadable firmware appears in “Terminal Reference” section on page 12. For the PL110−and IEC−specific commands terminals refer to sections “PL110 Firmware Commands” and “IEC Firmware Commands” respectively.
For the terminal for ROM firmware, refer to [10, 13].

[20] If you did not receive this file please contact *Software.Development@onsemi.com.*

[21] Note that this MIB parameter is common for the PL110 and IEC firmware. In general, MIB parameters are firmware-specific.

At least one other node must be configured in order to test power-line communication. Use another second terminal to connect to a second evaluation board, repeat all steps of *"Configuring the Modem"*section, and configure the modem with the same parameters, except for the MAC address:

```
set 1000=21
set 1002=8
set 4101=1 (for a 60 Hz mains)
set 4102=1
```

Starting Basic Communication

Once the modems are active, use the command *txmac* in one terminal to transmit communication frames through the MAC layer. The expected parameters are the number of frames to transmit[22], the destination address, domain address, payload and frame flags. The addresses and flags should be entered in hexadecimal format. As an example,

```
txmac 100, 21, 8, 10, 4
```

will try to send 100 frames to individual address 0031_H, domain address 55_H with the standard frame format. To abort the transmission, use stop.

Each transmitted frame has a payload of 10 bytes with the hard-coded value AA_H.

It is also convenient to use the broadcast address 0. Broadcast frames are always repeated by the transmitter and the confirmation sent back to the host is always positive. For instance

```
txmac 20, 0, 0, 10, 4
```

will broadcast 20 frames.

If the modem is transmitting, the yellow LED TxEn will light up; if a modem is receiving a correct frame, the green CRC LED will blink. This can help in debugging communication.

When another modem receives the transmitted frames and the frame destination address matches the address of the modem, it will report them in the terminal.

For a graphical representation, type *spy*. The separate "spy window" will open and indicate the number of received frames and signal to noise ratio for the specified carrier frequencies.

As an alternative to *txmac*, use the command *txmacm* to transmit 4 bytes of user data through the MAC layer. As an example,

```
txmacm 10, 20, 80, 4, 12345678
```

will try to send 10 frames to individual address 0020_H, domain address 80_H with the standard frame format. Each transmitted frame will have a payload of 4 bytes with content 12345678_H.

Table 2. TRANSMISSION FLAGS OF THE PL110 txmac AND txmacm COMMANDS

Bit	Name	Value	Description
0−1	Priority	00_B 01_B 10_B 11_B	System Normal Urgent Low
2	Frame Type	0 1	Extended Standard
3	Repeat	0 1	Do Not Repeat Repeat Frame
4	Destination	0 1	Individual Address Group Address

The last argument of both the *txmac* and the *txmacm* commands control the frame control flags. The flags, and their possible values, are listed in Table 2.

Access to Different Network Layers

It is possible to disable the MAC layer and order the firmware to transmit physical frames directly.

A minimal configuration when working with PHY layer requires disabling the MAC and activating the modem:

```
set 400=1
set 4102=1
```

Subsequently the command *txphy* can be used; expected parameters are the number of frames to transmit, the payload and bus idle delay. As an example,

```
txphy 100, 10, 50
```

will try to send 100 frames[22] to individual address $AAAA_H$[23], domain address AA_H[23] with the frame format chosen by the payload number. Transmitted frames have a payload of two bytes with the hard-coded value of AA_H. The bus idle delay specifies minimum elapsed time since the last transmission before the transmission of the new frame starts; measured in T_{bit} times, its maximum value is 255.

Note that by its nature, reception in PHY mode does not filter frames based on destination address; thus, all frames will be reported by any modem that receives them.

Additional Features

The PL110 firmware does not require the zero-crossing detection. This allows it to communicate over DC lines. However, this feature must be specifically enabled with the MIB parameter MIB_R_MISC_ZCGEN_MODE:

```
set 4201=1
```

To use dual channel operation, the parameter MIB_R_CONF_DUAL_CHAN must be set to 1.

[22]For field tests, it is useful to put the number of frames to a very high number.

[23]This address is hard-coded in the terminal.

Using the IEC Firmware

The IEC protocol is based on a master-slave organization. The slaves cannot communicate directly.

The IEC protocol also defines the synchronization method. A master will synchronize as soon as it is configured. On the other hand, a slave modem will only synchronize from the moment it correctly received a frame, even if the frame's destination address is different from the slave's address. As a result, all slaves should become synchronized to the master in due time. Refer to the IEC specifications for more information about synchronization.

You will need to configure one evaluation board as master and at least one other board as slave to test communication. Some scripts are prepared and available under the *cfg* folder in the installation folder. These may be called with the command *script*[24].

The IEC terminal also supports the Linky firmware. Linky is a standard based on IEC [2].

Configuring the Master Modem

By default, a master is configured with MAC address $C01_H$. This value can be changed by accessing the "Local MAC address" parameter in the MIB.

The IEC protocol requires synchronization to the mains before the master can send data. By default, the firmware assumes a mains frequency of 50 Hz. If 60 Hz is used, the MIB parameter MIB_R_CONF_MAINS_FREQ must be set accordingly:

```
set 4101=1
```

The *script master.txt*, provided in your installation, can then be used to configure a modem as master:

```
script cfg/master.txt
```

Configuring a Slave Modem

Please note that you need to open an new terminal if you already assigned the previous terminal to master configuration (required if you want to evaluate PLC communication between two nodes). Open a new terminal, and follow *"Starting the Terminal"* and *"Configuring the Modem"*sections for the additional evaluation board.

By default, a slave starts with address FFEH (the value defined for "new" participants in the IEC standard).

Load the default *slave.txt* or a custom script to configure the modem in slave mode[25]

```
script cfg/slave.txt
```

It is possible, and often convenient, to create customized scripts; as an example, for adjusting the baud rate or carrier pair frequencies. Several masters can operate in parallel. However, they must use different frequency pairs not to interfere with each other.

Starting Basic Communication

The master can be ordered to start to broadcast frames continuously with the *txllc* command. As an example

```
txllc 100, 12, 34, fff, 0
```

will transmit 100 frames (first parameter) to the MAC address FFF_H (the broadcast address) with initial credit 0[26]. To abort the transmission, use *stop*.

It is recommended to put the number of frames to a very high number for a field test.

In the slave terminal(s), you should observe log messages indicating that frames are being received. In addition, the slave should report after receiving the first frame that it is now synchronized.

You may also open spy windows (depicted in Figure 8) with the *spy* command: this allows monitoring the signal and noise levels[27]. The current levels are displayed by the four top bars; the historical levels are rendered in the graph below.

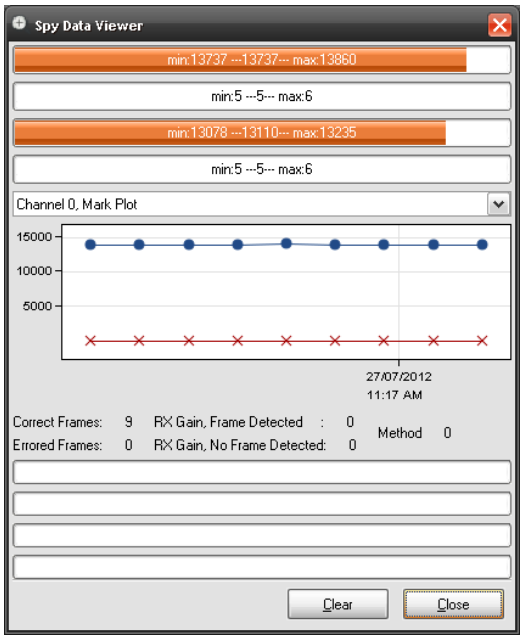

Figure 8. The Terminal Spy Window Graphically Shows the Current and Historical Signal and Noise Levels

Access to Different Network Layers

The IEC firmware from ON Semiconductor implements the three lowest layer defined by the IEC 61334 standard (refer to [6, 7]): the physical (PHY), Media Access Control (MAC) and Logical Link Layer (LLC) layers.

[24]Refer to "Advanced Terminal Features" section for details.

[25]As with the master, MIB 4101 must be set to 1 if the local mains frequency is 60 Hz before running the configuration script.

[26]The initial credit specifies how many times the frame will be repeated by slave modems that are configured as repeater. Repetition with credit counter is a technique to extend the transmission range by having salves repeat messages that don't address the slave. For more information, refer to [7].

[27]Note that the in-band (i.e., with each received frame) transmission of the signal and noise values needs to be enabled by the set 3300 = 1 command. The default scripts include this command.

The user can transmit and receive frames at different layers of the network stacks with the MIB parameter MIB_TOPLAYER_ID (6100).

By default all three are enabled (6100 = 2). To disable the LLC layer and expose the MAC layer, use set 6100 = 1. To enable only the physical layer, use set 6100 = 0.

Note that the MIB_TOPLAYER_ID is only writeable before the modem is configured, that is, before set 4102 = [mode]. After configuration, is read only MIB_TOPLAYER_ID. To make it writeable again, issue the *reset* command. All OID values will be reset to their default value.

In the previous section, frames were transmitted using the physical, MAC and LLC layers. The command *txmac* may be used to transmit frames with the specified number of frames, destination address and initial number of credits[28]. As an example,

```
reset
download IEC.bin
set 6100=1
set 4102=1 (2 for slave)
txmac, 10, FFF, 0
```

will send configure the modem as a master and send 10 frames to the broadcast address FFFH with initial credit of 0. The transmitted frames have only one sub-frame and the payload is 12 times byte AA_H.

Similarly, the command *txphy* may be used to transmit frames with the MAC layer disabled too. As an example,

```
reset
download IEC.bin
set 6100=0
set 4102=1
txphy 10
```

will transmit 10 dummy PDUs.

Using the Test Firmware

Specific firmware is available to generate a test pattern on the transmit output pin. This can be useful for development and production testing. Loading the firmware enables the *test* command (see *"Test Firmware Commands" section*). As an example,

```
reset
download testmode.crc.bin
set 4101=1 (for a 60 Hz mains)[29]
set 580C=1942
test 0, 1, 0
```

will generate a continuous 74 kHz sinewave.

Advanced Terminal Features

- The *log <level>* command alters the amount of logging information shown. Use *log −1* to disable all output; use *log 3* to shown as much logging as possible.
- By default the working directory of the terminal is the installation folder. This working directory affects the lookup of scripts, firmware binaries and configuration files if you specify relative paths for the relevant commands. It might be convenient to change to working directory with the *cdir* command; as an example

  ```
  cdir D:\PLC\Files
  ```

Troubleshooting Functionality

Setting up communication, as described in *"Using the PL110 Firmware"* or *"Using the IEC Firmware"*section, is a fairly involved process. As a result, an error is easily made.

This section describes how to debug *functional* problems; performance problems are discussed in *"Troubleshooting Performance"* section.

To eliminate performance limitations, connect the two evaluation boards to a single power distribution strip. This ensures the attenuation between the transmitting and the receiving modem is minimized.

Then, make sure the firmware download succeeded. This can be tested with any MIB *get* command. For instance, the command *get 4101* − the result in the log window should indicate whether the modem is configured for a 50 Hz or a 60 Hz mains, or a DC network. If the command fails, retry the download procedure described in *"Configuring the Modem"* section.

Once the firmware is up and running, configure one of the evaluation boards as a transmitter[30]. Try to transmit a large number frames and observe the yellow TXEN (transmit enable) LED. During the transmission of each frame, the line driver is enabled and the LED should light up briefly. The output of the modem itself may also be monitored on the test point MTx with an oscilloscope[31]. Short transmission bursts, one for each frame, with a steady voltage in-between are expected.

If you do not observe this, the modem does not transmit frames. Make sure it is correctly configured as a transmitter and try again.

---

[28]The destination address should be entered in hexadecimal format and the initial credit can be maximum 7 and minimum 0.

[29]Note that the test firmware, as the other firmware options, depends on the correct setting of the mains frequency. By default, 50 Hz is assumed.

[30]To do this, refer to "Configuring the Modems" section (ON−PL110 Firmware) or "Configuring the Master Modem" section (IEC Firmware).

[31]Note this is a small-signal, low-power signal generated by the 3.3 V analogue part of the modem. This signal is not output directly on the mains, but is amplified by the line driver.

If the modem does transmit, observe the red TSD (thermal shutdown) and ILIM (current limitation) LEDs[32]. If one of these LEDs are illuminated the line driver is overloaded. This can happen if the output level is too high or the line impedance is too low. To fix the problem, stop the current transmission and reduce the transmitted amplitude with the R_ALC_CTRL_VAL MIB parameter:

stop
set 5815=1 (or any value between 0–7)

This parameter sets the number of 3 dB attenuation steps, 0 corresponding to 0 dB attenuation, 7 to 21 dB attenuation. Try to maximize the transmitted amplitude, without overloading the line driver.

Once this is done, the transmitter is set up. Use an oscilloscope to verify the transmitted waveform on the test point PL of the transmitting daughterboard. This test point is connected to the output of the line driver, therefore the amplitude should be approximately 5–10 VPP, depending on the set transmission attenuation.

If a good signal is seen on MTx but not on PL, the usual cause is the choice of carrier frequencies. Appropriate carrier frequencies must be chosen the transmit filter of the transmitting daughterboard. Refer to *"EVK Filter Responses"* section for a list of daughterboard filters. If required, change frequencies (see *"Changing Carrier Frequencies"*).

If a strong signal is seen on the PL test point of the transmitter, observe the same test point on the receiver with another oscilloscope probe. An identical, somewhat attenuated, waveform should be seen.

If no signal is seen, the most likely cause is excessive attenuation in the coupling circuit[33]. Ensure appropriate carrier frequencies are selected for the type of motherboards[34]. Resonant motherboard only operate well with carrier frequencies close to the resonance frequency. For more details, refer to *"Changing Carrier Frequencies"* section.

Once a good waveform is seen on the test point PL on the receiving daughterboard, observe the signal at the input of the receiving modem (test point MRx). Here, too, a fairly signal is expected (about 1 VPP). If a strong signal is seen on PL but not on MRx, the carrier frequencies are not chosen correctly for the receive filter of the receiving daughterboard[35].

With an acceptable signal on the receiver test point MRx, communication should be possible. If the terminal associated to the receiving evaluation board does not indicate frames are being received, make sure the same carrier frequencies are used.

For the ON−PL110 protocol, also check that the addresses are set up correctly.

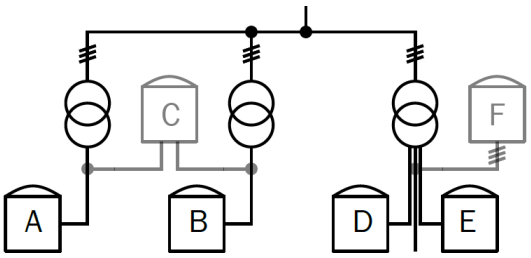

Figure 9. In this Example Grid, Modems A, B, D and E will have Difficulty Communicating Directly

If nothing helps, consider reversing the role of receiver and transmitter.

Attainable Communication Quality

The practical communication range strongly depends on the network. It is mainly influenced by the attenuation between the nodes and the noise level on the network.

As a rule, high and medium voltage networks have a simple, predictable topology with fairly low noise levels. As electrical loads are not directly connected to the network the impedance seen at the PLC frequencies is high, leading to low attenuation. Therefore, PLC is feasible over long ranges.

Conversely, low voltage networks are typically very hostile environments for PLC. This is especially true for residential and office networks. Electrical loads are directly connected to the network. Because many of these loads will have a capacitor across the power lines for EMC compliance, the attenuation at PLC frequencies is high. In addition, the many switching power supplies found in a typical home or office cause significantly higher noise levels.

The complex topology of an office or home network makes it very difficult to accurately predict the communication performance. As a rough guideline, expect up to a kilometer on medium voltage networks and up to a few hundred meters on low voltage networks.

It is important to remember that PLC signals usually cross transformers only with great attenuation.

---

[32]Note that the NCN49599 modem does not have a thermal shutdown indication pin, and no thermal shutdown LED is provided on NCN49599 daughterboards.

[33]Because the modems are connected on the same power distribution strip, the attenuation for PLC frequencies between the power outlets should be low, even in fairly heavily loaded environments.

[34]Also ensure the receiving modem board is not transmitting, thus blocking the signal from the other board. The state of the board (transmitting or receiving) is indicated by the TXEN LED.

[35]Again, refer to "EVK Filter Responses" section for a list of daughterboard filters.

Thus, communication across phases will often be impossible. In Figure 9, modems D and E will not see each other unless the three-phase modem F is configured as a repeater. Note that even in the same room, wall sockets are not necessarily connected to the same phase.

Even when modems are on the same phase, transformers cause problems: in Figure 9, modem A and B may not be able to communicate even though they are on the same phase. Adding a two-phase repeater (C) might solve the issue.

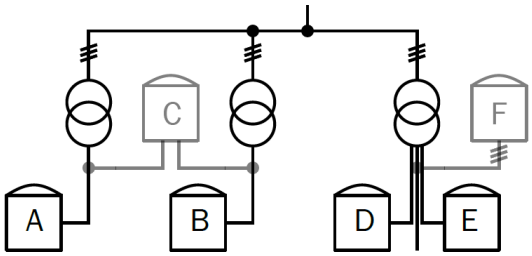

Figure 10. In this Sample Domestic Electrical Installation, the Television can Cause Significant Deterioration of the Communication Quality between Modems C and D

In addition, the presence of other consumers can block successful communication. In particular, switch-mode power supplies (SMPS) exhibit a very low impedance at PLC frequencies[36]. In Figure 10, the signal sent by modem D to C will be attenuated due to the presence of the television in between.

Referring to the same figure, another aspect becomes evident. Even though modem A and B are physically close, communication can be difficult due to the long *electrical* distance. Crosstalk with signals from modem C might also influence the communication.

Troubleshooting Performance

Sometimes, the communication quality is disappointing when using the evaluation kits in the field. To understand the underlying causes, it is very useful to study the local topology of the grid. The preceding section gives some clues where to look to try to understand the behavior:

- Are the evaluation kits on the same phase? If not, is it possible to add a repeater connected to both phases?
- How does the electrical installation plan look (frequently, this will be difficult to find)? If the cabling between two nodes is long, is adding a repeater feasible?
- How many consumers are connected to the network, in particular those with heavy switching power supplies located between the evaluation kits? Does the communication quality improve when disconnecting consumers?
- When two modems that are close-by (i.e., seeing little attenuation between them) are both configured as repeater, slight timing difference will cause the repeated frames to interfere destructively. Thus, the addition of a second repeater function will actually cause *worse* performance. In such a case, try configuring only one of these modems as a repeater.
- What disturbance is seen on the mains? In particular, interference on or near the carrier frequencies will significantly reduce the communication quality. However, interference away from the carrier will also cause problems if the amplitude − after filtering − is sufficiently high. Checking the waveform and spectrum of the signal at the modem input (test point MRx) will help to pinpoint this[37].
- What is the attenuation for each carrier frequency? Are the carriers by chance located at a notch of the signal transfer function of the network?

Changing Carrier Frequencies

It is evident from the previous section that it is often useful in a field test to change the carrier frequencies.

Ordering the modem to do this is easily done with the MIB parameters MIB_R_FS1 and MIB_R_FM1 (space resp. mark frequencies)[38]. The best-fitting hexadecimal value *A* corresponding to a given frequency f_C [Hz] is derived from

$$A = \left\| \frac{4096}{46875} \cdot f_C \right\| \qquad \text{(eq. 1)}$$

However, you must also consider the external filters when changing carriers. Both the reception and transmission signal path are filtered. Shifting away from the resonant frequency is liable to decrease the amplitude of a transmitted and received signal. Refer to the designed filter response for your daughterboard variant in *"EVK Filter Responses"* section to ascertain the exact result.

Similarly, if a motherboard with a resonant coupling circuit is used (refer to *"Mains Coupling"* section), deviating from the resonance frequency will cause signal attenuation[39].

---

[36]The cause of this high load is the presence of a filter capacitor at the input of a switch-mode power supply. The filter is required to comply with conducted EME standards.

[37]A spectrum analyzer may be used for this, but a digital oscilloscope with (offline or online) FFT is often more convenient. Note that an oscilloscope is severely limited in dynamic range compared to a spectrum analyzer.

[38]The PL110 firmware support dual-channel communication (i.e., four carriers) and therefore also supports the MIB parameters MIB_R_FS2 and MIB_R_FM2.

[39]This is especially true when the mains impedance is low.

Terminal Reference

Terminal-related Commands

The following commands are related to the terminal itself and its serial port. They are always available.

save [file name] Saves the logging in the log window of the PLC Terminal into a file.

- *file name.* The name and possibly path of the file to save to

version Displays the version of the PLC Terminal application.

oids Display all MIB object Ids.

exit Exits the PLC Terminal application (if a serial port is open, it is released).

open [port], [baud] Opens a serial port on the PC with a given baud rate.

- *port.* The name of the COM port (e.g. COM13)
- *baud.* The baud rate, depends on the daughterboard. Refer to page 6 for details

close Closes the port that is currently open.

ports Displays a list of all serial ports reported by the operating system, categorised in open and available ports.

log [level] Sets the logging level (the amount of logging output in the main window) of the terminal application.

- *level.* The logging level (0 to 3). A higher level generated more logging

spy Popup window with spy data.

rts [level] Sets the level of the RTS pin on the currently opened COM port. Note that RTS is the same as TREQ, so this command can be used to control start-up of the modem together with the SEN pin.

- *level.* The requested level (0 or 1)

dtr [level] Sets the level of the DTR pin on the currently opened COM port.

- *level.* The requested level (0 or 1)

clear Clears all output in the logging window.

script [file name] Executes a script file

- *file name.* The name and possibly path of the script file to execute

print [string] Outputs a specific string to the terminal window. This is particularly useful in scripts

- *string.* The character string to print

pause [sec] Halts execution of the currently running script during a given time, for example to allow the modem to respond.

- *sec.* The time to wait, in seconds

download [file name] Downloads the firmware as a binary image over the UART into the modem. Prior to using this command, the serial port must be open. This command will control the TREQ pin for you; the SEN pin must be manually driven low for the download to succeed. Refer to *"Modem Boot Sequence"* section on page 3 for details.

- *file name.* The name and possibly path of the binary firmware file

cdir [path to folder] Set current working directory for the terminal. The working directory is used as a base path when opening files specified with a relative path. Changing the working directory is useful to shorten the parameter of the commands *save*, *script* and *download.*

- *path to folder.* Valid path to any folder, e.g. C:\Projects\PL110

Common Firmware Commands

These commands are available when a serial port has been opened and firmware has been downloaded into the modem. Note that some MIB parameter are not writeable if the modem is configured[40].

set [parameter]=[value] Sets (writes) the value of a parameter in the modem's Management Information Base (MIB).

- *parameter.* The object ID of the parameter to be set, in hexadecimal format
- *value.* The value for the parameter

get [parameter] Gets (reads) the value of a parameter in the modem's Management Information Base (MIB)

- *parameter.* The object ID of the parameter to be read, in hexadecimal format

iset [parameter], [index], [value] Sets (writes) the value of an indexed parameter in the modem's Management Information Base (MIB).

- *parameter.* The object ID of the parameter to be set, in hexadecimal format
- *index.* The index of the value within the parameter
- *value.* The value for the parameter

iget [parameter], [index] Gets (reads) the value of an indexed parameter in the modem's Management Information Base (MIB).

- *parameter.* The object ID of the parameter to be set, in hexadecimal format
- *index.* The index of the value within the parameter

reset Asks the modem firmware to perform a reset. The modem will restart the boot sequence; this implies the firmware is lost and must be reloaded.

[40] The modem is configured once the MIB parameter 4102 (MIB_R_CONF_MODE) has been set to 1. This can be done only once; reset the modem and re-upload the firmware to revert to an unconfigured state.

PL110 Firmware Commands

These commands are only valid if the ON−PL110 firmware has been successfully loaded.

txphy [num], [cnt], [bit] Transmits a dummy PHY frame by consecutively sending a number of Phy Data Requests to the modem. The requests contain dummy data (all AA_H). Whether or not the transmission was successful is not regarded by this command; that is left to the user. This command is only available when the PHY layer of the modem is accessible; this is controlled with the Phy Direct Access MIB parameter.

- *num.* The number of requests to send
- *cnt.* The number of bytes within every request
- *bit.* Bus idle delay, measured in bit times, before the frame is sent on the power line by the PHY layer

txmac [num], [dmac], [dom], [cnt], [flgs]
Transmits a dummy MAC frame from the modem by consecutively sending a number of Mac Data Requests to the modem. The requests contain dummy data (all AA_H). Whether or not the transmission was successful is not regarded by this command; that is left to the user.

- *num.* The number of requests to send
- *dmac.* The destination MAC address of the frames
- *dom.* The destination domain address of the frames
- *cnt.* The number of bytes (payload data) of every request
- *flgs.* Frame flags; the binary-OR values of the bits specified in Table 2 on page 7

txmacm [num], [dmac], [dom], [flgs], [userdata]
Transmits a MAC frame from the modem by consecutively sending a number of Mac Data Requests to the modem. The requests contain the data requested by the user. Whether or not the transmission was successful is not regarded by this command; that is left to the user.

- *num.* The number of requests to send
- *dmac.* The destination MAC address of the frames
- *dom.* The destination domain address of the frames
- *flgs.* Frame flags. Refer to the *txmac* command for details
- *userdata.* The data to transmit as payload of the MAC frame, interpreted as a 32-bit number in decimal format

txdelay [msec] Set the pause time between transmit requests within commands *txphy, txmac* and *txmacm.*

- *msec.* The pause time in milliseconds

IEC Firmware Commands

These commands are only valid if the IEC firmware has been successfully loaded.

Note that the MAC and LLC layers of the IEC 61334 standard do not provide bit error detection in received frames or reception acknowledgement. Therefore, all transmission commands (*txphy, txmac, txmacm* and *txlcc*) handle transmission only; determining whether the frames were correctly received at the destination is a task for the user or the higher layers.

unsync Asks the modem to desynchronize by sending a PHY Synchronization Request. This command is only available when the physical layer of the modem is directly accessible; this is controlled with the MIB parameter 6100_H (TOPLAYER). To select the physical layer of the modem at top layer, set this parameter to 0.

txphy [num] Transmits a dummy PHY frame by consecutively sending a number of Phy Data Requests to the modem. The requests contain dummy data (all AA_H). This command is only available when the PHY layer of the modem is accessible; this is achieved by setting OID 6100 (TOPLAYER) to 0.

- *num.* The number of requests to send

txmac [num], [dmac], [ic] Transmits a dummy MAC frame from the modem by consecutively sending a number of Mac Data Requests to the modem. The requests contain dummy data (all AA_H). This command is only available when the MAC layer of the modem is accessible; this is achieved by setting OID 6100 (TOPLAYER) to 1.

- *num.* The number of requests to send
- *dmac.* The destination MAC address of the frames
- *ic.* The Initial Credit value to use

txmacm [num], [dmac], [ic], [userdata] Transmits a MAC frame from the modem by consecutively sending a number of Mac Data Requests to the modem. The requests contain the data requested by the user. This command is only available when the MAC layer of the modem is accessible; this is achieved by setting OID 6100 (TOPLAYER) to 1.

- *num.* The number of requests to send
- *dmac.* The destination MAC address of the frames
- *ic.* The Initial Credit value to use
- *userdata.* The data to transmit as payload of the MAC frame, interpreted as a 32-bit number in decimal format

txllc [num], [dsap], [ssap], [dmac], [ic]
Transmits a number of link layer data request frames (DL_Data.request). This command is only available when the LLC layer of the modem is accessible; this is achieved by setting OID 6100 (TOPLAYER) to 2 − the default value.

- *num.* The number of requests to send
- *dsap.* Destination Service Access Point
- *ssap.* Source Service Access Point
- *dmac.* The destination MAC address of the frames
- *ic.* The Initial Credit value to use

Test Firmware Commands

This command is only valid if the test firmware has been successfully loaded.

test [seconds], [mode], [pattern] Enable the line driver and start generating a test signal on the transmit output pin. The MIB parameters MIB_R_FS1, MIB_R_FM1 and MIB_R_ALC_CTRL_VAL influence the signal.

- *seconds*. The duration of the test signal fragment; specify 0 if the test signal should not stop
- *mode*. The type of signal to be generated:
  - 0: continuous single-tone transmission on the mark frequency
  - 1: continuous single-tone transmission on the space frequency
  - 2: alternating between mark and space frequency
  - 3: user-specified pattern
- *pattern*. If the mode parameter is set to 3, this parameter specifies the bits to be transmitted as a 32-bit word; otherwise it is ignored. As an example, the value 55555555 alternates between mark and space.

APPLICATION DESIGN MANUAL

To obtain the application design manual, please contact your sales representative.

APPENDIX

EVK Filter Responses

The transmit and receive filters on the EVK daughterboard are tuned to specific frequencies. Figures 11–18 show the frequency responses for the receive and transmit path for each of the available filters. Only the daughterboard response is shown, i.e. from connector to modem input resp. from modem output to connector. The motherboard also is frequency selective.

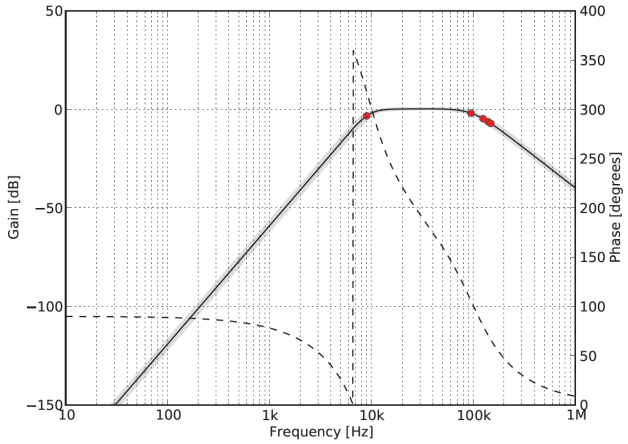

Figure 11. Designed Receive Path Frequency Response of a Daughterboard with “D” Filters

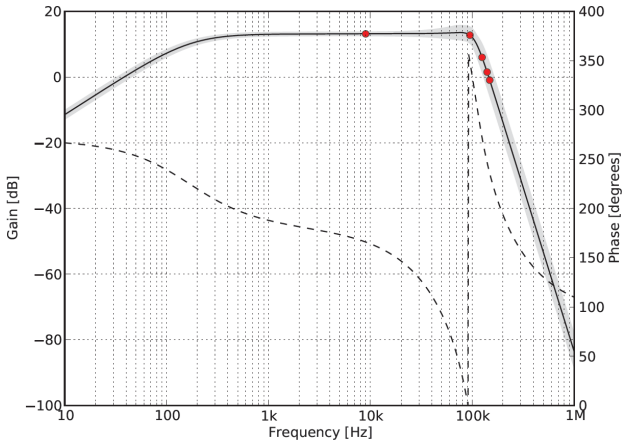

Figure 12. Designed Transmit Path Frequency Response of a Daughterboard with “D” Filters

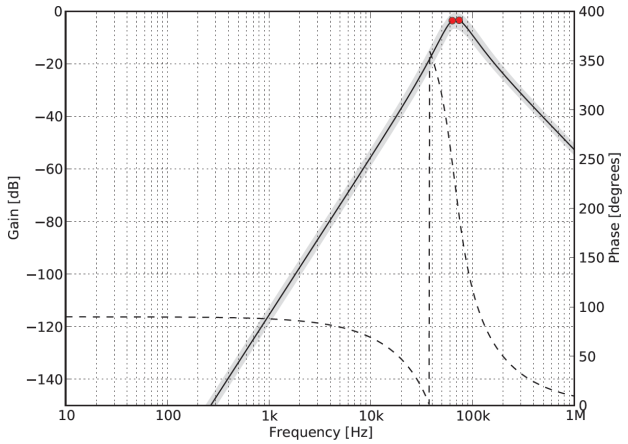

Figure 13. Designed Receive Path Frequency Response of a Daughterboard with “E” Filters. The IDIS Frequencies (63.3 and 74.5 kHz) are Marked

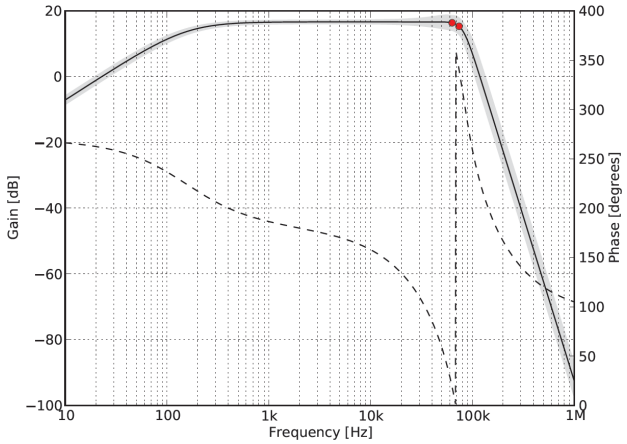

Figure 14. Designed Transmit Path Frequency Response of a Daughterboard with “E” Filters

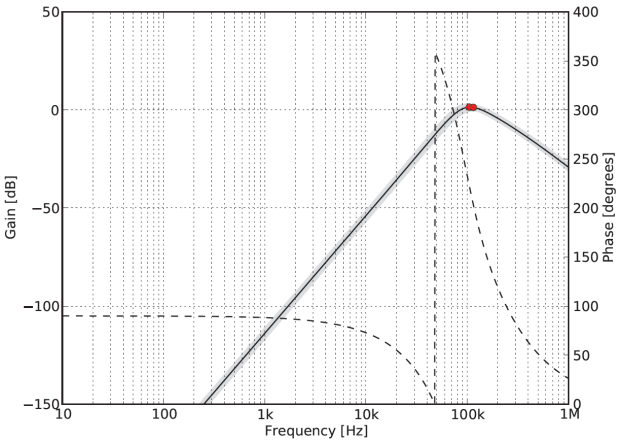

Figure 15. Designed Receive Path Frequency Response of a Daughterboard with “G” Filters. The PL110 Frequencies (105 and 115 kHz) are Marked

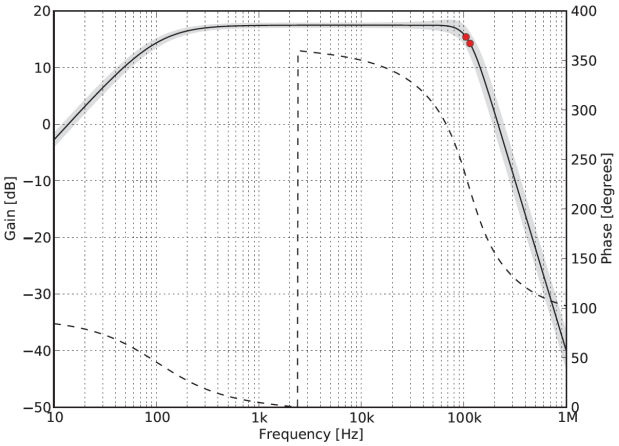

Figure 16. Designed Transmit Path Frequency Response of a Daughterboard with “G” Filters

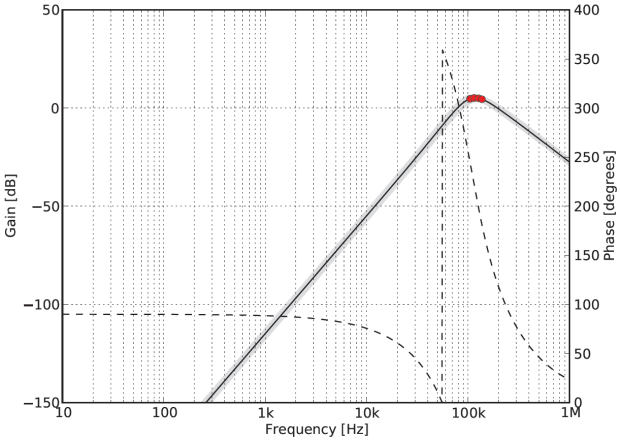

Figure 17. Designed Receive Path Frequency Response of a Daughterboard with “J” Filters. The PL110 Dual Channel Frequencies (105, 115, 127.5 and 137.5 kHz) are Marked

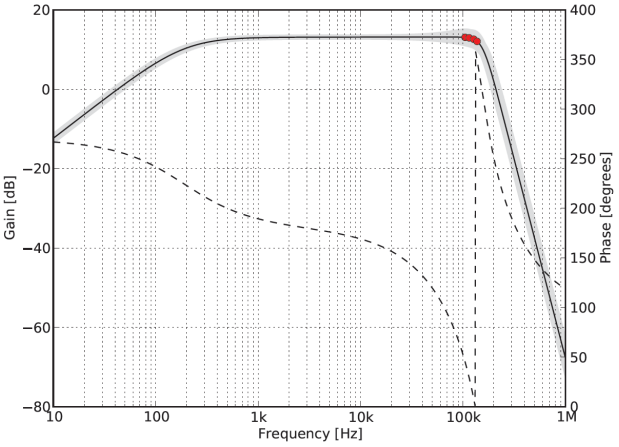

Figure 18. Designed Transmit Path Frequency Response of a Daughterboard with “J” Filters

Board Layouts

The copper design of the revision 6 motherboard and the revision 3 NCN49597 daughterboard are shown in Figures 19 and 20[41]. The bottom copper is shown mirrored, i.e. as if seen through the board.

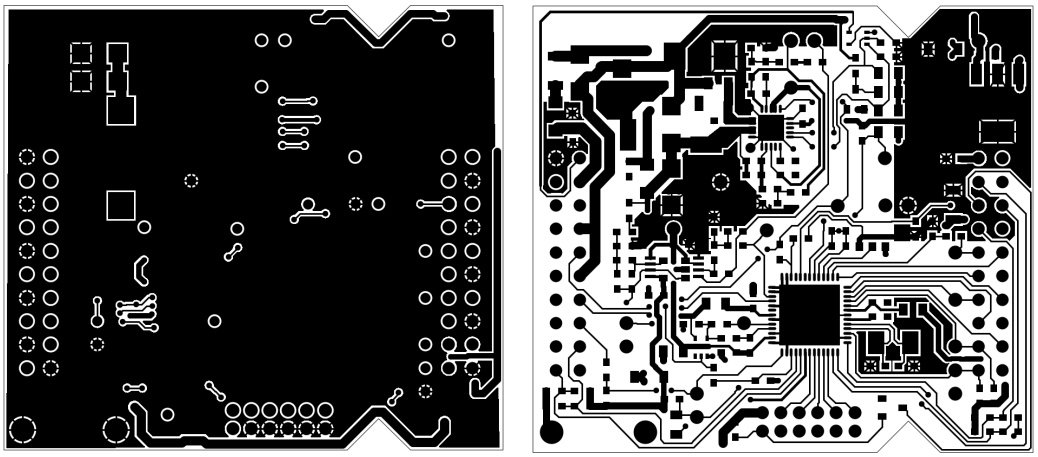

Figure 19. Layout of the Rev. 3 NCN49597 Daughterboard: Top Copper (Left) and Bottom Copper

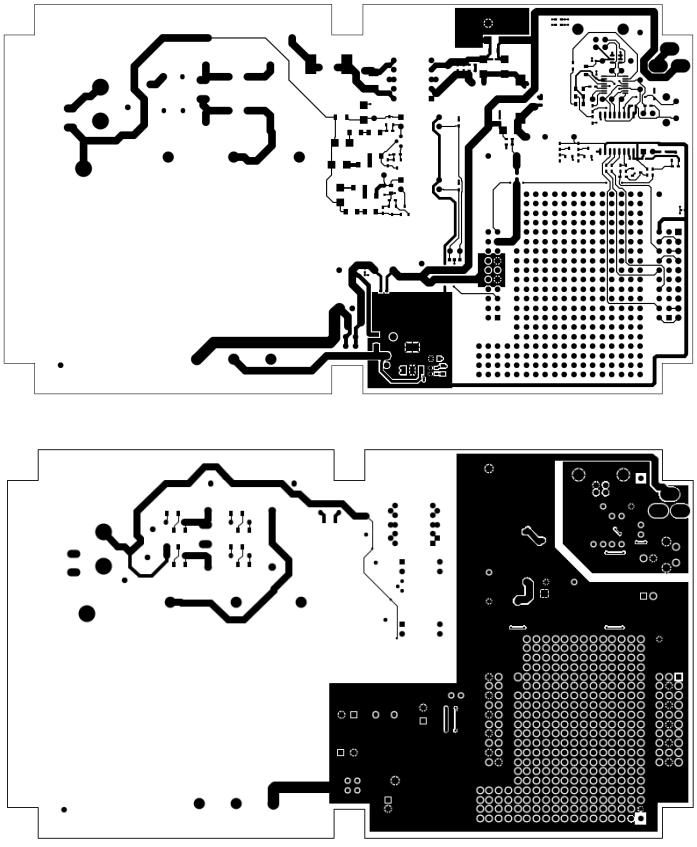

Figure 20. Layout of the Rev. 6 Motherboard: Top Copper (Top) and Bottom Copper

[41]Figures 19 and 20 are not to scale.

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